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AMBIENT LIGHT DETECTION CIRCUIT

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AMBIENT LIGHT DETECTION CIRCUIT

FIELD OF THE INVENTION

The present invention relates to photosensor circuits and more particularly to solid-state flat-panel displays having photosensors for sensing ambient illumination.

BACKGROUND OF THE INVENTION

Flat-panel displays such as liquid-crystal displays (LCDs) or organic light emitting diode (OLED) displays are useful in a wide variety of applications under a wide variety of environmental conditions. When viewed in a dark environment (little ambient radiation), such displays need not be as bright as when viewed in a lighter environment (more ambient radiation). If the display light output is adjusted periodically to compensate for ambient light conditions, the display can maintain a constant relative brightness with respect to the ambient illumination even if the ambient illumination changes. In a bright environment, this will increase display brightness to improve visibility. In a dark environment, this will increase display device lifetime and reduce power usage by reducing unnecessary display brightness.

The use of photosensors with displays to detect ambient light and adjusting the brightness of the display in response to ambient illumination is known. Efficient silicon photosensors are available and generally provide a current proportional to the light incident on the sensor. These photosensors are constructed on silicon substrates and may have a wide dynamic range. Such sensors can be combined with displays to provide ambient sensing. For example, see JP2002-297096-A, which describes a circuit for providing ambient compensation to an electroluminescent display. However, as implemented, the sensor is separate from the display and senses the light at a single point. This increases the cost, number of components, and size of the device and does not directly measure the light incident on the display itself.

It is known to integrate a light sensor on an active-matrix display device for the purpose of sensing light emitted from the display device itself. See, for example, US 6,489,631 issued December 3, 2002 to Young et al., which describes a display having integrated photosensors for sensing light emitted by a light emitting element of the display. There is no disclosure of the use of such photosensors for detecting ambient light, however, and the arrangement of the sensor coupled with a light emitter limits the size of the photosensor and its ability to sense ambient light.

When providing ambient compensation to a display, it is important that the light sensing device provide a signal having a wide dynamic range representative of the ambient illumination. The human visual system can effectively detect light from very dark ambient conditions of only a few photons to very bright outdoor conditions greater than 75,000 lux. However, tests conducted by applicant demonstrate that photosensors constructed on flat-panel displays using thin-film technology do not have the efficiency of photosensors constructed on silicon substrates and do not have the sensitivity necessary to provide a signal representative of lower light levels, for example < 100 cd/m2, where displays are often used. Nor do they have the dynamic range necessary to accommodate the range of the human visual system.

There is a need therefore for an improved photosensor circuit for the detection of ambient light, particularly within an active-matrix flat-panel display.

SUMMARY OF THE INVENTION

The need is met according to the present invention by providing a circuit for detecting light comprising: a) a light-integrating photo-sensor circuit having one or more thin-film photosensors and being responsive to a variable integration period signal and to ambient light for producing a photo signal representing the intensity of the ambient light, wherein the photo signal may be in one of at least three states including a no-signal state, an in-range state, and a saturated state; and b) a control circuit for receiving the photo signal and

automatically increasing the period of the integration period signal when the photo signal is in the no-signal state and decreasing the period of the integration period signal when the photo signal is in the saturated state so as to result in the photo signal being in the in-range state and producing a corresponding ambient light signal.

In particular embodiments of the invention, the circuit for detecting light is employed as a component of a flat panel display, wherein the display comprises a substrate and a plurality of light-emitting elements located thereon in a display area; and the one or more thin-film photosensors of the light-integrating photo-sensor circuit are located on the substrate, and being responsive to a variable integration period signal and to ambient light for producing a photo signal representing the intensity of the ambient light incident on the flat-panel display.

In a further embodiment, the invention is directed towards a method for controlling a flat-panel display, comprising: a) providing a flat-panel display comprising a substrate and a plurality of light-emitting elements located thereon in a display area; b) providing a light-integrating photo-sensor circuit having one or more thin-film photosensors located on the substrate and responding to a variable integration period signal and to ambient light for producing a photo signal representing the intensity of the ambient light incident on the flat-panel display, wherein the photo signal may be in one of at least three states including a no-signal state, an in-range state, and a saturated state; c) iteratively receiving the photo signal and automatically increasing the period of the integration signal when the photo signal is in the no-signal state and decreasing the period of the integration signal when the photo signal is in the saturated state so as to result in the photo signal being in the in-range state and producing a corresponding ambient light signal; and d) adjusting the brightness of the flat-panel display in response to the ambient light signal.

The invention enables an improved dynamic range for thin-film photosensors, particularly when used with a flat-panel display.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a schematic diagram of a photosensor circuit according to one embodiment of the present invention;

Fig. 2 is a schematic diagram of a display system utilizing the photosensor circuit of Fig. 1;

Fig. 3a is a schematic diagram of a photosensor and control circuit according to an embodiment of the present invention;

Fig. 3b is a schematic diagram of a photosensor and control circuit according to another embodiment of the present invention; and

Fig. 4 is a schematic diagram of a control circuit according to an embodiment of the present invention.

DETAILED DESCRIPTION OF THE INVENTION

Referring to Fig. 1, the present invention includes a circuit **10** for detecting ambient light on a display comprising a light integrating photosensor circuit **12** having one or more thin-film photosensors **14** located on a flat-panel display substrate, connected to a detection circuit **16**, and being responsive to an integration period signal **32** and to ambient light (as detected by photosensor **14**) for producing a photo signal **20** representing the intensity of the ambient light incident on the flat-panel display. The photo signal has at least three states including a no-signal state, an in-range state, and a saturated state. A control circuit **30** receives the photo signal **20** and automatically increases the period of the integration signal **32** when the photo signal is in the no-signal state and decreases the period of the integration signal **32** when the photo signal is in the saturated state so as to maintain the photo signal in the in-range state.

Referring to Fig. 2, a flat-panel display **40** includes a plurality of light emitters **42** in a display area **41** integrated on the flat-panel display substrate **43** and responsive to control signals **34** from the control circuit **30**. The photosensor **14** is integrated on the same substrate as the light emitters **42**. The detection circuit **16** may also be integrated with photosensor **14** in photosensor control circuit **12** on the same substrate, as shown in Fig. 2. The photo signal **20**

produced by the photosensor circuit **12** is connected to the external control circuit **30**. Alternatively, some or all of the control circuit **30** may be integrated on the substrate.

In operation, the control circuit **30** is responsive to an input signal **38** and drives the display using control signals **34**. Ambient light incident on the display is also incident on the photosensor **14** and the photosensor circuit **12** produces a photo signal **20** representative of the amount of ambient light incident on the display. The photosensor circuit **12** is an integrating circuit, that is the circuit integrates a signal from the photosensor over a period of time to produce the photo signal **20**. Such integrating circuits are more sensitive than circuits that directly detect current produced by a photosensor in the presence of light. The integration signal **32** specifies the period of the integration. The more frequent the integration signal, the shorter the integration period. The less frequent the integration signal, the longer the integration period.

The photo signal **20** is in one of at least three states. The first state is a "no-signal" state and is seen when so little ambient light is incident on the display **40** that any decrease in the ambient light will not further reduce the value of the photo signal **20**. The second state is an "in-range" state and is seen when sufficient ambient light is incident on the display **40** to provide a photo signal **20** having a value representative of the ambient light incident on the display **40**. The third state is a "saturated" state and is seen when so much ambient light is incident on the display **40** that any increase in the ambient light incident on the display **40** will not further increase the value of the photo signal **20**. Because, as demonstrated by applicant, thin-film photo-sensors typically have a limited sensitivity and dynamic range, whenever the ambient light incident on the display **40** is out of the photosensor **14** range, the photo signal **20** will be in either a "no-signal" or "saturated" state.

The control circuit **30** responds to the photo signal **20** by adjusting the period of the integration signal **32**. If the photo signal **20** is in a "no-signal" state, the integration period is increased to provide more time for the photo-sensor **14** to accumulate a signal representative of the ambient light incident on the

display **40**. If the photo signal **20** is in an "in-range" state, the period of the integration signal remains unchanged. If the photo signal **20** is in a "saturated" state, the period of the integration signal **32** is reduced to provide less time for the photo-sensor **14** to accumulate a signal responsive to the ambient light incident on the display **40**. This process of adjusting the integration signal period is repeated until the photo signal **20** is in the "in-range" state. The value of the integration signal **32** period and the photo signal **20** together represent the amount of ambient light incident on the display **40**. Once the photo signal is in-range, the control circuit **30** modifies the input signals **38** according to the value of the photo signal **20** to produce control signals **34** to drive the light emitters **42** and compensate for any ambient light incident on the display **40**. When a relatively brighter ambient illumination is detected, the control signals **34** drive the light emitters **42** to produce a brighter display output. When a relatively darker ambient illumination is detected, the control signals **34** drive the light emitters **42** to produce a dimmer display output.

A suitable photosensor circuit is disclosed in co-pending, commonly assigned U.S. application Serial No. 10/694,560, the disclosure of which is hereby incorporated by reference. The integration signal **32** may be a digital signal that periodically restarts the photosensor signal integration. The sensitivity to ambient illumination of this photosensor circuit may be adjusted by modifying the size of the photosensor or the value of the circuit components. When in the in-range state, the photo signal **20** output from the photosensor circuit is an analog value that represents the amount of ambient light incident on the display **40**. When the output is at a ground voltage, the photo signal is in a "no-signal" state. When the output is at the voltage used to provide power to the circuit, the photo signal is in a "saturated" state. When the voltage is between zero and the power voltage, the photo signal is in the "in-range" state and represents the ambient illumination incident on the display.

The control circuit may be an analog control circuit and use analog techniques for controlling the period of the integration signal and modifying the input signal to produce a control signals **34** to compensate for ambient

illumination. Such techniques are known in the art, for example using operational amplifiers, transistors, capacitor, and resistors.

Alternatively, digital means may be employed to control the period of the integration signal. Referring to Fig. 3a, two photosensor circuits **12a** (for relatively low light detection) and **12b** (for relatively higher light detection) are employed having different sensitivities to ambient illumination. Different sensitivities may be obtained, for example, by adjusting capacitance in the photosensor circuit, by adjusting the size of the photosensor **14**, by locating different filters over the photosensors, by using different periods for the integration signals, or by adjusting the aspect ratio or configuration of the photosensors.

The photo signals **20** may be applied to digital circuits such as an AND gate **50**, as shown, with or without inverters. When applied to a digital circuit gate, the photo signal **20** will be in a saturation state when the photo signal **20** reaches the switching voltage for the gate. When the photo signal does not reach the switching voltage for the gate, it is in a "no-signal" state. Thus, the individual photo signals **20** indicate in one state that the ambient illumination incident on the display **40** generates a signal below the switching voltage and in the other state that the ambient illumination incident on the display generates a signal above the switching voltage. Taken together, however, the binary signals **70, 72, 74** and **76** output from the AND gates **50** represent four possible photo signal states. Thus, when both photo signals **20** are HIGH, the ambient illumination is above the threshold for the less sensitive photosensor circuit **12b,** representing a saturation state with signal **70**. When both photo signals **20** are LOW, then the ambient illumination is below the threshold for the more sensitive photosensor circuit **12a,** representing a no-signal state with signal **72**. When the photo signal **20** from the more sensitive circuit is HIGH and the photo signal **20** from the less sensitive photo-sensor circuit **12b** is LOW, the ambient illumination is between the thresholds of the two photosensor circuits **12a, 12b,** representing an in-range state with signal **74**. When the photo signal **20** from the less sensitive

circuit **12b** is HIGH and the photo signal **20** from the more sensitive photo-sensor circuit **12a** is LOW, there is an error state, represented by signal **76**.

By adjusting the sensitivities of the two photosensor circuits **12a, 12b,** and the period of the integration signal **32**, any particular detection range may be obtained. For example, if one photosensor circuit is set with a switching threshold at ambient light levels of 1000 cd/m^2 and a second is set with a switching threshold at ambient light levels of 5000 cd/m^2, the circuit will detect three light levels: 0-1000 cd/m^2, 1000-5000 cd/m^2, and > 5000 cd/m^2, for a given integration signal period. If the integration signal period is then reduced, for example by half, the three light levels may detect signals in the range of 0-500, 500 – 2,500, and > 2,500 cd/m^2. Alternatively, the integration signal may be doubled so that the three light levels may detect signals in the range of 0 – 2,000, 2,000-10,000, and > 10,000 cd/m^2.

If the signal from the two circuits does not indicate an in-range state, the period of the integration signal **32** may be adjusted until it does. If the sensitivity of the two photosensor circuits **12a, 12b** are relatively close, for example differ by only 20%, the accuracy of the ambient light detection can be very good. In this case, by adjusting the period of the integration signal until an "in-range" state is achieved, the ambient illumination may be measured to an accuracy of 20%.

Referring to Fig. 3b, an alternative arrangement may be employed having a single photo-sensor **12**. In this arrangement, external LOW signal **54** and HIGH signal **56** are compared to the photo signal **20** using comparators **52**. If the photo signal **20** is comparable to the LOW signal **54**, a no-signal state is indicated with signal **72**. If the photo signal **20** is comparable to the HIGH signal **56**, a saturated signal **70** is indicated. If neither state is indicated the photo signal **20** is in-range. In this case, the controller **30** receives three signals and responds as described above. The comparators **52** may include operational amplifiers and the controller **30** may digitize the analog photo signal **20** using analog-to-digital converters as is known in the art.

A suitable digital mechanism for implementing an auto-ranging capability is shown in Fig. 4. Referring to Fig. 4, the saturation-state signal **70** and no-signal-state signal **72** from the AND gates **50** are connected to an up/down digital counter **60**. The counter **60** stores a value representing the period of the integration signal **32**. A clock signal **64** increments or decrements the value stored in the counter **60** depending on the state signals. The value of the counter (shown as an 8-bit value) is loaded into a down counter **62** (e.g., by using an inverse of the clock signal). A count signal **66** then decrements the down counter until it reaches 0 at which point the output of the down counter **62** provides the integration signal **32** to reset the photosensor circuit **12**. The process is iterated until an "in-range" signal **74** is obtained. Counters, clock signals, and the digital logic necessary to implement such a circuit are well known in the art.

The thin-film photosensor **14** may be any thin-film light-sensitive device suitable for use within a flat-panel display system. For example, silicon or organic photodiodes, photocapacitors or phototransistors may be employed. Thin film materials may be deposited, e.g., by evaporation or photolithographic processes as known in the art (typically in layers less than 1 micrometer thick). These photosensors and circuit elements may be integrated with a flat panel display to provide an integrated solution. When integrated with a display, any portion of, or all of, the circuit **12** may be constructed using thin-film transistors and electrical components as are known in the flat-panel display art.

A typical flat panel display includes a rigid or flexible substrate, typically made of glass or plastic, together with a plurality of light-emitting elements, such as organic light emitting diode materials (OLEDs) or light controlling elements having polarizing layers in combination with an emissive back light, such as an LCDs. The individual light emitting elements may be controlled using thin-film transistors and capacitors together with an external controller to provide data, power, and timing signals.

A plurality of thin-film photosensors **14** can be electrically connected in common to provide one integrated photo signal or, alternatively, they can be separately addressed or their output combined. The plurality of

photosensors **14** may be located near each other or dispersed over the flat-panel display **40**. A greater number or size of integrated photosensors **14** can increase the signal, thereby improving the responsiveness of the ambient light detection. These may, or may not, have a common detection circuit **16** but will utilize a single control circuit **30**. Moreover, the photo signals **20** will be more representative of the overall ambient illumination incident on the display since, if a portion of the display is shadowed, having several sensors can provide several signals that can be averaged to produce an overall average of the illumination incident on the display area.

The present invention may be used in both top- and bottom-emitting OLED flat-panel display devices. The light emitting display **40** may be an organic light emitting diode (OLED) display that includes multiple supporting layers such as light emitting layers, hole injection, hole transport, electron injection, and electron transport layers as is known in the art. Any or all portions of the photosensor circuit **12** may be deposited in a common step with active-matrix display circuitry and may include identical materials to simplify processing and manufacturing. As demonstrated by applicant, thin-film structures used for active-matrix OLED displays may be employed to form the photosensors **14** and detection circuit **16**. There are a variety of ways in which the photosensors can be connected that depend on various factors such as the layout of the display and the conductivity of the electrodes and signal lines connected to the photosensors.

Any or all of the detector circuit **16** or control circuit **30** can be integrated directly onto the same substrate as the display device **40** or it can be implemented externally to the display **40**. In general, higher performance and greater accuracy can be achieved by integrating the circuitry directly with the display device but this may not be desirable for all display devices.

In a preferred embodiment, the invention is employed in a flat-panel device that includes Organic Light Emitting Diodes (OLEDs) which are composed of small molecule or polymeric OLEDs as disclosed in but not limited to US 4,769,292, issued September 6, 1988 to Tang et al., and US 5,061,569,

issued October 29, 1991 to VanSlyke et al. Many combinations and variations of organic light emitting displays can be used to fabricate such a device.

The invention has been described in detail with particular reference to certain preferred embodiments thereof, but it will be understood that variations and modifications can be effected within the spirit and scope of the invention.

PARTS LIST

10	circuit
12	photosensor circuit
12a	photosensor circuit
12b	photosensor circuit
14	photosensor
16	detection circuit
20	photo signal
30	control circuit
32	integration signal
34	control signals
38	input signals
40	flat-panel display
41	display area
42	light emitters
43	display substrate
50	AND gate
52	comparator
54	LOW signal
56	HIGH signal
60	up/down counter
62	down counter
64	clock signal
66	count signal
70	saturation-state signal
72	no-signal-state signal
74	in-range-state signal
76	error-state signal